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<p>(54) Title: REFLECTIVE FLAT-PANEL DISPLAY DEVICE</p> <p>(57) Abstract</p> <p>The invention relates to a reflective flat-panel display device (1) comprising a display panel (3) which is suitable for modulating an illumination beam with image information. The display panel (3) comprises a diffusing liquid crystalline material (5) and a first and a second substrate (7, 9) enclosing the liquid crystalline material (5). The display device (1) also comprises an absorbing element (10). The display panel (3) includes means which reflect light at an angle of incidence which is larger than a given angle of incidence <math>\theta_c</math>.</p> <div data-bbox="836 1165 1307 1942"> </div>		

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Reflective flat-panel display device.

The invention relates to a reflective flat-panel display device comprising a display panel which is suitable for modulating an illumination beam with image information, the display panel comprising a diffusing liquid crystalline material and a first and a second substrate enclosing the liquid crystalline material, the display device also comprising an  
5 absorbing element.

In reflective display devices having a diffusing display panel, it is relatively difficult to render the black state and the white state sufficiently black and white, respectively. Generally, the transparent state of the panel is used to realize the black state by  
10 providing an absorbing element on the side of the display panel facing away from the incident light. However, this has the result that the white state is not sufficiently bright. To obtain a bright white state, a reflector is required which reflects the light forwardly diffused by the active layer of the display panel into the viewing direction. When, for example a metallic mirror is used for this reflector, a very bright white state can be realized, but this is  
15 at the expense of the black state.

A reflective flat-panel display device of the type described in the opening paragraph is known from, for example United States Patent US-A 5,408,344. In the display device described in this Patent, the above-mentioned problem is solved by providing a prism foil outside the display panel. One part of the light incident on the prism foil is reflected,  
20 whereas the other part of the light will be transmitted by the prism foil so as to be subsequently absorbed by an absorbing element.

A drawback of the display device known from said United States Patent is that shadow images will occur in the case of a directed illumination. Moreover, an external reflector requires a large aperture. If the aperture is not maximal, due to, for example the  
25 presence of a black mask, the effect of the external reflector and consequently the luminance rapidly decrease. This is caused by the fact that the reflections on the glass-air interface and the external reflector occur behind the pixels so that a black mask is to be passed through twice.

It is an object of the invention to provide a bright reflective flat-panel display device in which the above-mentioned problems are obviated. To this end, the reflective flat-panel display device according to the invention is characterized in that the display panel includes means which reflect light at an angle of incidence which is larger than  
5 a given angle of incidence  $\Theta_c$ .

Since the means are present within the display panel, the occurrence of shadow images is reduced considerably. Since only light from a given angle of incidence will be reflected, substantially perpendicularly incident light will be mainly passed towards the absorbing element where it will consequently be absorbed. In this way, the black state, i.e.  
10 the case for the transparent state of the pixels of the liquid crystalline material, will be very satisfactory to the viewer watching the exit face of the display panel within a given viewing angle. Moreover, the white state, i.e. the case for the diffusing state of the pixels of the liquid crystalline material, will be optimized because the means behave as a reflector for angles outside the viewing angle. Moreover, it is sufficient to use a relatively thin liquid  
15 crystalline layer.

A first embodiment of the reflective flat-panel display device according to the invention is characterized in that the means comprise an angle-dependent reflector which is situated between the liquid crystalline material and the second substrate.

The light which is forwardly diffused by the diffusing liquid crystalline  
20 material is incident on the reflector and, dependent on the angle of incidence, it will be reflected or not reflected. In the transparent state of the liquid crystalline material, the light is passed towards the absorbing element for that part of the incident light which would yield reflections within the viewing angle. In the diffusing state of the liquid crystalline material, all the light is diffused in the layer, and the angle of incidence on the display panel is hardly  
25 important. Now, much more light will be incident on the reflector at large angles of incidence, so that the white state will be observed as being very bright.

A further drawback of the display device known from said United States Patent is that a prism foil is active in one direction only. If an even distribution of the reflections is desired, it is not sufficient to provide prisms in a single direction, but relatively  
30 complicated structures are to be used. This drawback is obviated by an embodiment of the reflective flat-panel display device according to the invention, which is characterized in that the reflector comprises a stack of dielectric layers and behaves as a cut-off filter.

Dielectric layers reflect rotational-symmetrically. Moreover, this aspect of the present invention is based on the recognition that, for a dielectric stack behaving as a cut-

off filter, a maximal quantity of light will be passed upon a substantially perpendicular incidence for a given wavelength range, whereas substantially all the light will be reflected from a given angle of incidence  $\Theta_c$ . The wavelength at which the transmission is still 50% for perpendicular incidence is referred to as the cut-off wavelength. Above this wavelength,  
5 there is reflection, whereas light having shorter wavelengths will be passed.

The reference  $\Theta_c$  is understood to mean the angle of incidence within the display panel on the relevant means.

A further embodiment of the reflective flat-panel display device according to the invention is characterized in that  $500 \text{ nm} \leq \lambda_c \leq 650 \text{ nm}$  for the cut-off wavelength  
10  $\lambda_c$  of the cut-off filter.

A satisfactory white state, a satisfactory black state and an optimum contrast of the display device can be realized at a cut-off wavelength within the above-mentioned interval.

Another embodiment of the reflective flat-panel display device according to the invention is characterized in that the reflector has at least one pair of cholesteric layers  
15 which are reflective in the same wavelength range and have opposite directions of polarization rotation.

A cholesteric layer is a liquid crystalline layer having a cholesteric ordering. This means that the molecules of the material spontaneously order in solution to a  
20 helical or helix-like structure having a pitch  $p$ . After such a solution has been provided as a thin, active layer between two parallel substrates, the helix-like structure is directed in such a way that the axis of the helix will be transverse to the layer.

When an unpolarized beam is incident on a cholesteric polarizer, the levorotatory and the dextrorotatory circularly polarized beam components will be separated  
25 from each other. In fact, a beam component having the direction of rotation which corresponds to the direction of the helix will be reflected, whereas the beam component having the other direction of rotation will be passed. Whether a beam component is passed or not passed is, however, not only determined by the direction of rotation but also by the wavelength of the incident beam. The reflection wavelength  $\lambda_0 = 1/2 (n_o + n_e) p$ . Only the  
30 part of the beam component having the direction of rotation corresponding to the direction of the pitch and being within the wavelength band  $\lambda_0$  will be reflected. Since the light should not be polarized in the application described above, there should always be two cholesteric layers per wavelength range, namely a levorotatory and a dextrorotatory layer so that both directions of polarization, i.e. the full beam, will be reflected within the relevant wavelength

range.

Another embodiment of the display device according to the invention is characterized in that the reflector is a holographic liquid crystalline material.

5 A holographic liquid crystalline material is understood to mean a PDLC layer in which a refractive index modulation is produced because the photopolymerization has taken place in a three-dimensional intensity distribution realized by interfering light beams.

An example of such an element is described in the article: "Optimization of holographic PDLC for reflective color display applications" by K. Tanaka et al. in SID 95 DIGEST, pp. 267-270.

10 Another embodiment of the reflective flat-panel display device according to the invention is characterized in that the means comprise an angle-dependent diffusor.

An angle-dependent diffusor may be used instead of an angle-dependent reflector. An example of an angle-dependent diffusor is described in, for example, the article "A novel polymer film that controls light transmission" by M. Honda et al. in Progress in  
15 Pacific Polymer Science 3 (1994), pp. 159-169.

An angle-dependent forward diffusor is transmissive to all angles of incidence but has a diffusing effect within a given angular range. After this diffusion, a large part of the diffused light reaches the substrate-air interface on which total internal reflection will occur, so that the light will eventually reach the exit face of the display panel.

20 The diffusor may also be used in combination with, for example, one of the above-mentioned angle-dependent reflectors. In that case, the reflection occurs on this reflector instead of on the air-substrate interface. The forward diffusor is then arranged, for example, between the liquid-crystalline material and the angle-dependent reflector.

The diffusor may also be a backward diffusor. This means that the  
25 diffusor has the effect of a diffusing reflector for a given range. The diffusor may be situated, for example, between the liquid crystalline layer and the second substrate. In that case, neither an angle-dependent reflector nor a substrate-air interface are necessary.

In all these possibilities, the diffusor ensures that the ultimately reflected light is diffuse light.

30 Another embodiment of the reflective flat-panel display device according to the invention is characterized in that the diffusor is anisotropic gel.

An anisotropic gel is very suitable for this use, inter alia, because it may be implemented as a very thin film, and is known per se from, for example, European Patent Specification 0 451 905.

Another embodiment of the reflective flat-panel display device according to the invention is characterized in that the diffuser is an oriented diffusing liquid crystalline material.

In this case, a given orientation of the liquid crystalline material is frozen.

5

A further embodiment of the reflective flat-panel display device according to the invention is characterized in that the display device includes an extra reflector.

The extra reflector ensures that the reflection of light having wavelengths falling outside the wavelength bands, in which the angle-dependent reflector or the angle-dependent diffuser are active, is optimized. In this way, an optimum luminance is obtained through a large wavelength range, so that unwanted color effects are suppressed.

The use of an internal and an extra reflector, which may be external or internal, yields more freedom in considering which fraction of the light must be reflected internally and which fraction remains to be reflected by the extra reflector.

15

If the total reflection is partly ensured by a specular reflector, a diffuser is preferably used in combination therewith so as to ensure that the reflection is diffuse at the angles at which this is possible. Within the viewing angle, the diffuser should be transparent, whereas outside this angle, i.e. at oblique angles, it should function as a diffuser.

The extra reflector may be, for example, a specular reflector, such as a prism foil, or an angle-dependent diffuse reflector, an example of which was mentioned hereinbefore. If the extra reflector is a diffuse reflector, the extra diffuser may be dispensed with.

These and other aspects of the invention are apparent from and will be elucidated with reference to the embodiments described hereinafter.

25

In the drawings:

Figs. 1(a) and 1(b) show embodiments of a reflective flat-panel display device according to the invention, provided with an angle-dependent reflector in the dark and the bright state, respectively, the absorbing element being situated outside the display panel;

Figs. 2(a) and 2(b) show embodiments of a reflective flat-panel display device according to the invention, provided with an angle-dependent reflector in the dark and the bright state, respectively, the absorbing element being situated within the display panel;

Figs. 3(a), 3(b), 3(c) and 3(d) show some embodiments of a reflective

flat-panel display device according to the invention, provided with an angle-dependent diffusor;

Fig. 4 shows an embodiment of a reflective flat-panel display device according to the invention, provided with an angle-dependent diffuse reflector;

5 Fig. 5 shows an embodiment of a reflective flat-panel display device according to the invention, provided with a prism foil, and

Fig. 6 shows a graph in which the reflection characteristic for a dielectric stack having a cut-off wavelength of 560 nm is represented for red, blue and green light as a function of the internal and external angles of incidence.

10

The flat-panel display device 1 shown in Figs. 1(a) and 1(b) comprises a diffusing display panel 3. Such a display panel comprises a first substrate 7 and a second substrate 9 enclosing a diffusing liquid crystalline layer 5, for example, a PDLC layer (polymer dispersed liquid crystal) as an optically active medium. The PDLC layer consists of, for example, a liquid crystalline material which is dispersed in the form of drops in a transparent polymer material. Moreover, an electrode layer 11, 13 is situated between each of the substrates 7, 9 and the layer 5. The liquid crystalline layer is divided into pixels which are driven by the electrodes by means of a voltage source 12. Within pixels for which no voltage is applied across the electrode layer, as in Fig. 1(b), the molecules within the drops have a given net orientation, but the orientation among the drops themselves is different. These pixels are in diffusing state. When a voltage is applied to the electrodes (Fig. 1(a)), the molecules will direct themselves in accordance with the same orientation within the corresponding pixels. These pixels are in a transparent state. For the sake of simplicity, the Figures show the full PDLC layer in the same state.

25 The display panel 3 of the display device 1 further includes means which ensure that light having an angle of incidence which is larger than  $\Theta_c$  is reflected, whereas light which is incident at a smaller angle of incidence will be passed and absorbed by an absorbing element 10. In this way, a relatively dark black state is obtained in the viewing direction for the viewer. In Figs. 1(a) and 1(b) the absorbing element 10 is situated outside the display panel 3.

30 The display device may be illuminated, for example by means of ambient light. In many cases, this light includes directed illumination such as, for example, from a lamp. The device may also be illuminated by means of peripheral illumination. For example, the light may be coupled into the second substrate which then functions as a waveguide. In



the drawings, the illumination, directed or undirected, is diagrammatically denoted by the reference numeral 8.

The means may be constituted, for example, by an angle-dependent reflector 15 which is present between the PDLC layer 5 and the second substrate 9. When a light beam is incident on the display panel 3, the light reaches the PDLC layer 5 first.

Fig. 1(a) shows an embodiment in which the PDLC layer is in a transparent state, whereas Fig. 1(b) shows an embodiment in which the PCLC layer is in a diffusing state.

When the layer 5 is in a transparent state (Fig. 1(a)), the light beams  $b_1$  and  $b_2$  are passed unhindered to the reflector 15. The reference  $b_1$  denotes a light beam having an angle of incidence  $\Theta_1$  which is smaller than  $\Theta_c$ , and the reference  $b_2$  denotes a light beam having an angle of incidence  $\Theta_2$  which is larger than  $\Theta_c$ .  $\Theta_c$  is the critical angle as from which reflection occurs. Light having an angle of incidence which is smaller than  $\Theta_c$  will be passed. If  $b_1$  is incident on the reflector 15, then this light will be passed by the reflector 15 towards the absorbing element 10 and will thus be absorbed. A conventional value for  $\Theta_c$  is  $20^\circ$ - $25^\circ$ . In air, this corresponds to a viewing angle of approximately  $30^\circ$ - $40^\circ$  for the viewer 6. If  $b_2$  is incident on the reflector 15, then this light will be reflected, again reach the PDLC layer 5 and will be passed unhindered towards the exit face 14 of the display device 1. For the viewer 6, the transparent state of the pixels of the PDLC layer 5 thus corresponds to the dark state of the display panel 3. The radiation incident within the viewing angle of a viewer 6 is absorbed, whereas the radiation incident outside this viewing angle will be reflected from the viewing angle.

When the layer 5 is in a diffusing state (Fig. 1(b)), the light incident on the display device 1 is diffused in the layer 5. This Figure shows only one light beam  $b$ , because the diffusion within the PDLC layer applies to all directions of incidence and, consequently, should not be distinguished from each other. Due to the diffusion within the PDLC layer, the beam incident on the reflector 15 has all directions of incidence. Light which is incident on the reflector 15 at an angle of incidence  $\Theta_i$  which is larger than  $\Theta_c$  will be reflected again, whereas light having angles of incidence which are smaller than  $\Theta_c$  will be passed. On its way to the exit face 14, the light reflected on the reflector 15 will be diffused again within the PDLC layer. The result is that a considerable part of the light incident on the display panel will occur in the viewing direction of the viewer 6. The display panel is then in the bright state.

The spatial angle which is bounded by  $\Theta_c$  is relatively small with respect

to the total spatial angle, so that a relatively small quantity of light will be lost for the bright state when realizing a satisfactory dark state within the viewing angle of the viewer.

Figs. 2(a) and 2(b) show embodiments for the dark and bright state, respectively, of the display panel, in which the absorbing element 10 is situated in the display panel 3. The electrode and absorption function may be combined in a single layer, for example, in a black chromium layer. When the absorbing element is integrated in the display panel, the switches and addressing lines of the display panel may be burned in under the electrodes of the reflective pixels, so that a relatively high aperture can be realized.

A very suitable reflector is a stack of dielectric layers which behaves as a cut-off filter. Such a stack reflects in an angle-dependent manner. A cut-off filter is a filter which passes a maximal quantity of light of a part of the spectrum for a given wavelength range, while substantially the full spectrum will be reflected from a given angle of incidence  $\Theta_c$ . The wavelength at which the transmission is still 50% for perpendicular incidence is referred to as the cut-off wavelength. There is reflection above this wavelength, whereas light having shorter wavelengths will be passed.

The angle dependence of a dielectric reflector is, however, not the same for all wavelengths and is generally considered to be a drawback. However, this embodiment of the present invention is based on the recognition that the wavelength-dependent angle dependence can be utilized to realize a bright display device which, moreover, has a relatively satisfactory dark state.

$\Theta_c$  can be chosen by means of the number of layers and the material of which the layers are made.

A very suitable reflector is a stack of dielectric layers whose cut-off wavelength  $\lambda_c$  ranges between 500 nm and 650 nm. Such a reflector allows combination of a satisfactory white state, a satisfactory black state and an optimum contrast. At small angles of incidence, the reflector described is transmissive to blue and green and, as much as possible, to red. For larger angles of incidence, both red, blue and green light are reflected. Fig. 6 shows a reflection characteristic of a dielectric stack having a cut-off wavelength of 560 nm as a function of the internal and the external angles of incidence. The external angle of incidence is the angle measured on the exit face 14 of the display panel. The internal angle of incidence is the angle measured on the reflector within the display panel. The stack may be considered to be a short-wavelength pass filter.

Another embodiment of an angle-dependent reflector is constituted by a stack of at least two cholesteric layers. A cholesteric layer is a liquid crystalline layer having

a cholesteric ordering. This means that the molecules of the material spontaneously order in solution to a helical or helix-like structure having a pitch  $p$ . After such a solution has been provided as a thin, active layer between two parallel substrates, the helix-like structure is directed in such a way that the axis of the helix will be transverse to the layer.

5                   When an unpolarized beam is incident on a cholesteric polarizer, the levorotatory and dextrorotatory circularly polarized beam components will be separated from each other. In fact, a beam component having the direction of rotation which corresponds to the direction of the helix will be reflected, whereas the beam component having the other direction of rotation will be passed. Whether a beam component is passed or not passed is, 10 however, not only determined by the direction of rotation but also by the wavelength of the incident beam. The reflection wavelength  $\lambda_0 = 1/2 (n_o + n_e) p$ . Only the part of the beam component having the direction of rotation corresponding to the direction of the pitch and being within the wavelength band  $\lambda_0$  will be reflected.

                  Since the light should not be polarized in the application described above, 15 there should always be two cholesteric layers per wavelength range, namely a levorotatory and a dextrorotatory layer so that both directions of polarization, i.e. the full beam, will be reflected within the relevant wavelength range. There will thus always be an even number of cholesteric layers in the stack.

                  An angle-dependent reflector may be alternatively constituted by a layer 20 of a holographic liquid crystalline material. Such a material is known, for example, from the publication "Optimization of holographic PDLC for reflective color display applications" by K. Tanaka et al. in SID 95 Digest, pp. 267-270. Such a reflector consists of a polymer matrix in which liquid crystalline drops are ordered in surface areas. This surface area structure is obtained by means of photopolymerization-phase separation on the basis of a 25 holographic technique. The reflection wavelength is determined by the angles at which the holographic illumination is performed.

                  The above-mentioned means may comprise an angle-dependent diffusor 17 instead of an angle-dependent reflector 15. The diffusor may be either a forward or a backward diffusor.

30                   An angle-dependent forward diffusor passes all angles of incidence but operates as a forward diffusor in a given angular range. Outside this range, the incident light is passed substantially undisturbed. In combination therewith, reflection should occur elsewhere in the device for the radiation diffused within the relevant angular range. Figs. 3(a) and 3(b) show an embodiment for the transparent and the diffusing states, respectively,

of the PDLC layer 5 in which the reflection is ensured by an angle-dependent reflector 15.

When the display panel is in a transparent state (Fig. 3(a)), a beam  $b_1$  having an angle of incidence which is smaller than  $\Theta_d$ , the critical angle as from which diffusion occurs, will be passed towards the absorbing element 10. A beam  $b_2$  having an angle of incidence which is larger than  $\Theta_d$  will be diffused in the diffuser 17. Subsequently, the light is incident on the reflector 15. Light rays having an angle of incidence which is smaller than  $\Theta_c$  will be passed towards the absorbing element 10, whereas light rays having an angle of incidence which is larger than  $\Theta_c$  will be reflected. Again, diffusion will occur in the diffuser 17 for angles of incidence which are larger than  $\Theta_d$ .

When the display panel is in a diffusing state (Fig. 3(b)), additional diffusion will occur in the PDLC layer and already all angles of incidence will be present in the light incident on the diffuser and coming from the PDLC layer.

Figs. 3(c) and 3(d) show the case for the transparent and diffusing states of the display panel in which the reflection is ensured by the interface 19 between the second substrate 9 and air. The diffusion is analogous to that shown in Figs. 3(a) and 3(b). Now, reflection occurs in the form of total internal reflection on the interface 19 instead of on an angle-dependent reflector.

In Figs. 3(a) to 3(d), the absorbing element 10 may be alternatively arranged within the display panel instead of outside this panel.

There are several possibilities for the angle-dependent diffuser. A first possibility for an angle-dependent diffuser is an anisotropic gel. An example thereof is described in European Patent Specification EP 0 451 905, to which reference is made for more details.

In another possibility, the diffuser comprises an oriented liquid crystalline material. This is, for example, a PDLC layer in which a given orientation of the molecules is frozen.

Moreover, the display device 1 may be as yet provided with an extra reflector 21. Figs. 4 and 5 show some embodiments of this reflector.

In Fig. 4, the extra reflector 21 is implemented as an angle-dependent diffuse reflector. Such a reflector is not necessarily an external reflector but may be alternatively arranged within the display panel, for example, between the angle-dependent reflector 15 and the second substrate 9. The reflector 21 may be alternatively arranged on the lower side of the second substrate 9.

In Fig. 5, the extra reflector 21 is implemented as a prism foil and thus

necessarily as an external reflector. Moreover, a prism foil is a specular reflector. If the total reflection is partly ensured by a specular external reflector, a diffuser 23 is preferably used in combination therewith so as to ensure that the reflection is diffuse at the angles at which this is possible. Within the viewing angle, the diffuser should be transparent, whereas outside  
5 this angle, i.e. at oblique angles, it should function as a diffuser. Such a diffuser may consist of, for example, a transparent plate provided with a PDLC layer which is transparent within the viewing angle and has a diffusing effect outside this angle. This is a PDLC layer having an angle-dependent haxe.

The embodiments shown in Figs. 3(a) to 3(d) may also be provided with  
10 an extra reflector between the second substrate 9 and the absorbing element 10 or within the display panel itself.

The diffuser 23 is denoted by means of a broken line. The diffuser 23 may be alternatively arranged between the prism foil 21 and the absorbing element 10.

The extra reflector 21, either external or not external, ensures that the  
15 reflection of light having wavelengths falling outside the wavelength bands, in which the angle-dependent reflector 15 or the angle-dependent diffuser 17 are active, is optimized so that unwanted color effects are suppressed. Since the greater quantity of light is already reflected by the internal reflector, the occurrence of shadow images will be suppressed also in this case in which an external reflector is used. In fact, the extra reflector only acts on the  
20 light whose wavelength was not suitable for the angle-dependent reflector or the angle-dependent diffuser. The diffusion which is illustrated on the right-hand side of the display device shown in Fig. 5 will only be applicable to a very limited quantity of light. Moreover, due to the diffuse character of this reflection, all angles of incidence will be present in the reflected light, so that a part of this light will remain outside the viewing angle.

25 In Figs. 4 and 5, the PDLC layer 5 is shown as a layer having both diffusing pixels 2 and transparent pixels 4. A light beam  $b_1$  having an angle of incidence  $\theta_1$  which is smaller than  $\theta_c$  will be passed by a transparent pixel 4 and also by the angle-dependent reflector 15 and the extra reflector 21, so that the light beam will be absorbed by the absorbing element 10. Light which is incident at these angles on transparent pixels will  
30 not come within the viewing angle of the viewer. Consequently, these pixels are in the dark state for the viewer who is watching the panel within the viewing angle. For a pixel in the diffusing state, the light diffused within the pixel will be incident on the angle-dependent reflector at substantially all angles of incidence. The light for which the angle of incidence is large enough to be principally reflected, but whose wavelength is not exactly suitable for the

angle-dependent reflector, will as yet be reflected towards the extra reflector 21.

In Fig. 4, the absorbing element 10 may be arranged within the display panel if the diffuse reflector 21 is situated within this panel.

If the extra reflector is a diffuse reflector, the extra diffusor 23 may be  
5 dispensed with.

CLAIMS:

1. A reflective flat-panel display device comprising a display panel which is suitable for modulating an illumination beam with image information, the display panel comprising a diffusing liquid crystalline material and a first and a second substrate enclosing the liquid crystalline material, the display device also comprising an absorbing element,  
5 characterized in that the display panel includes means which reflect light at an angle of incidence which is larger than a given angle of incidence  $\Theta_c$ .
2. A reflective flat-panel display device as claimed in Claim 1, characterized in that the means comprise an angle-dependent reflector which is situated between the liquid crystalline material and the second substrate.
- 10 3. A reflective flat-panel display device as claimed in Claim 2, characterized in that the reflector comprises a stack of dielectric layers and behaves as a cut-off filter.
4. A reflective flat-panel display device as claimed in Claim 3, characterized in that  $500 \text{ nm} \leq \lambda_c \leq 650 \text{ nm}$  for the cut-off wavelength  $\lambda_c$  of the cut-off filter.
5. A reflective flat-panel display device as claimed in Claim 2, characterized  
15 in that the reflector has at least one pair of cholesteric layers which are reflective in the same wavelength range and have opposite directions of polarization rotation.
6. A reflective flat-panel display device as claimed in Claim 2, characterized in that the reflector is a holographic liquid crystalline material.
7. A reflective flat-panel display device as claimed in Claim 1, 2, 3, 4, 5 or  
20 6, characterized in that the means comprise an angle-dependent diffusor.
8. A reflective flat-panel display device as claimed in Claim 6, characterized in that the diffusor is an anisotropic gel.
9. A reflective flat-panel display device as claimed in Claim 6, characterized in that the diffusor is an oriented diffusing liquid crystalline material.
- 25 10. A reflective flat-panel display device as claimed in any one of the preceding Claims, characterized in that the display device includes an extra reflector.

1/6

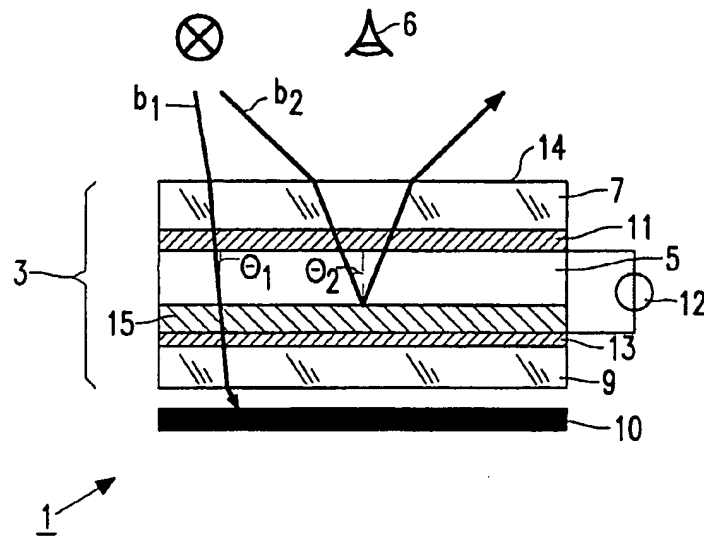
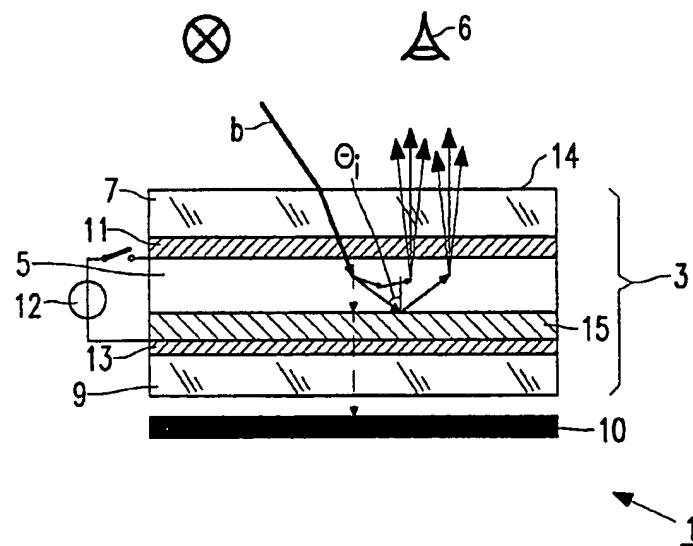


FIG. 1a



**FIG. 1b**





3/6

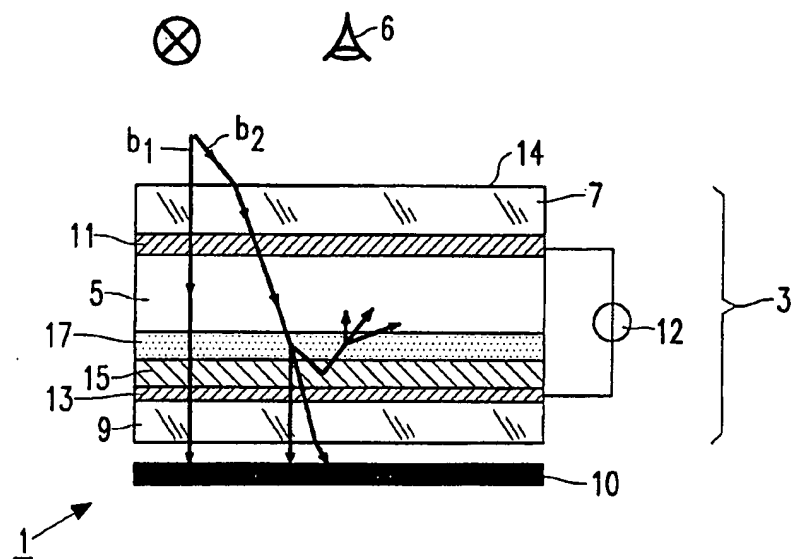


FIG. 3a

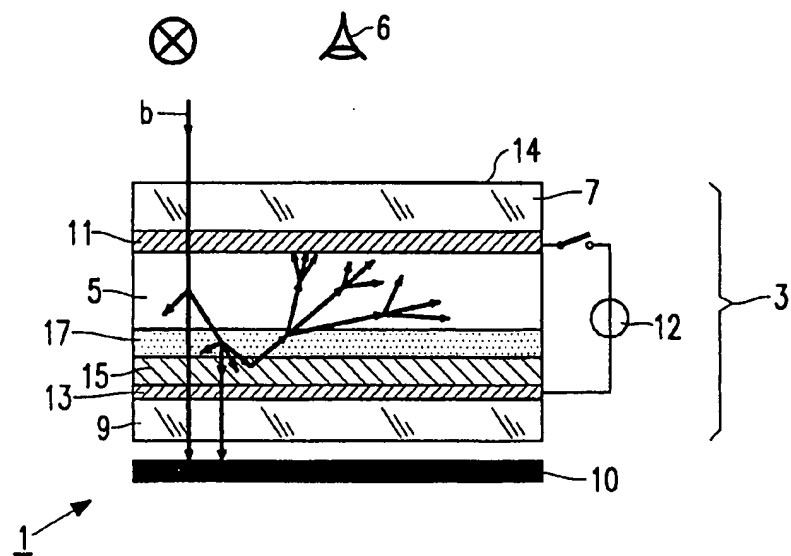


FIG. 3b

4/6

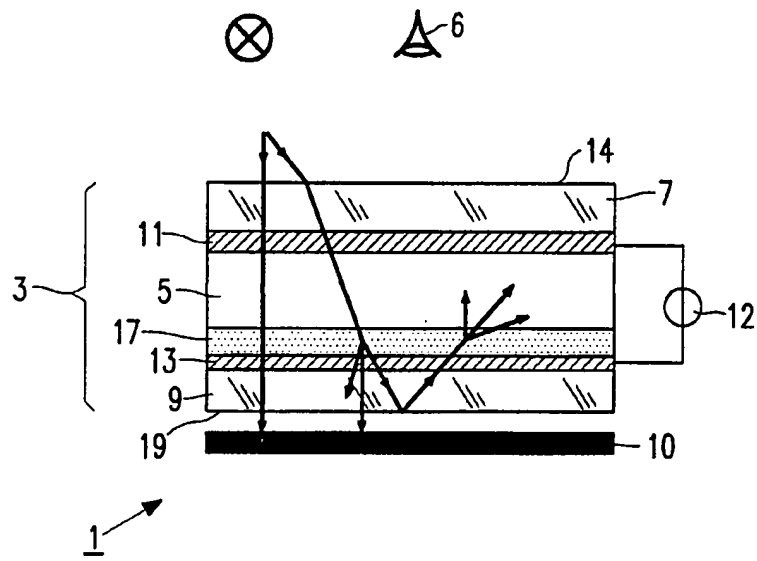


FIG. 3c

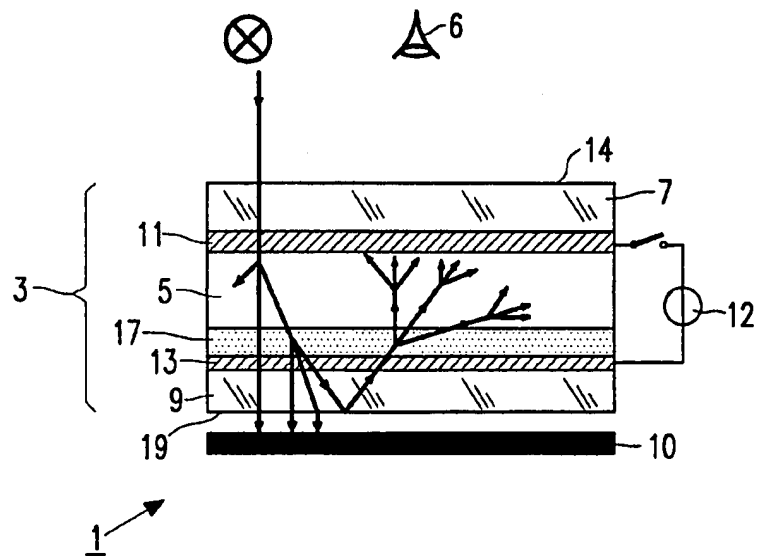


FIG. 3d

5/6

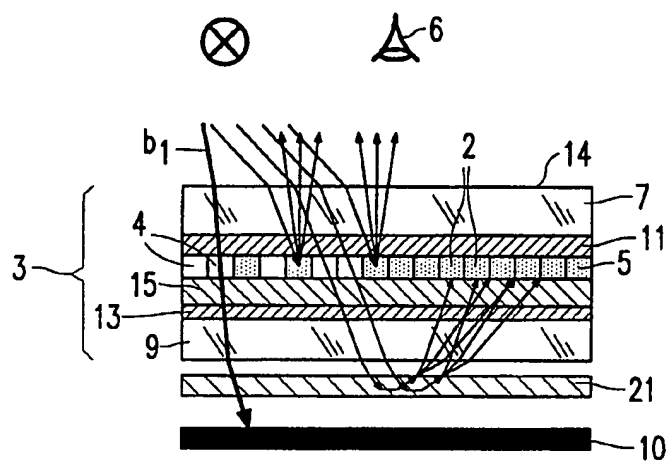


FIG. 4

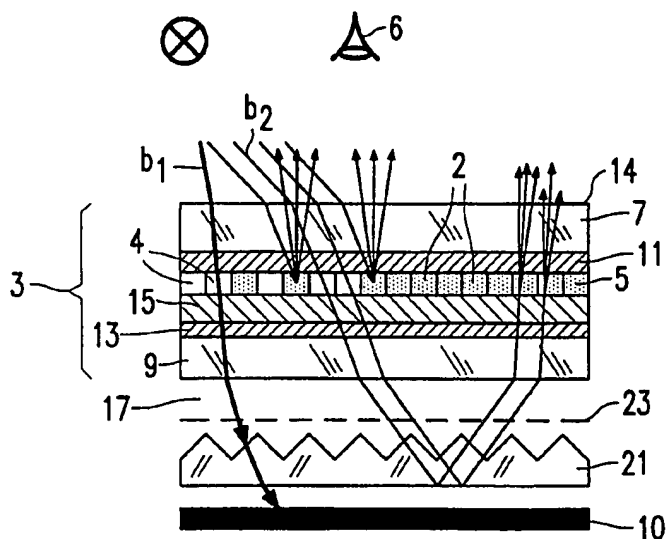


FIG. 5

6/6

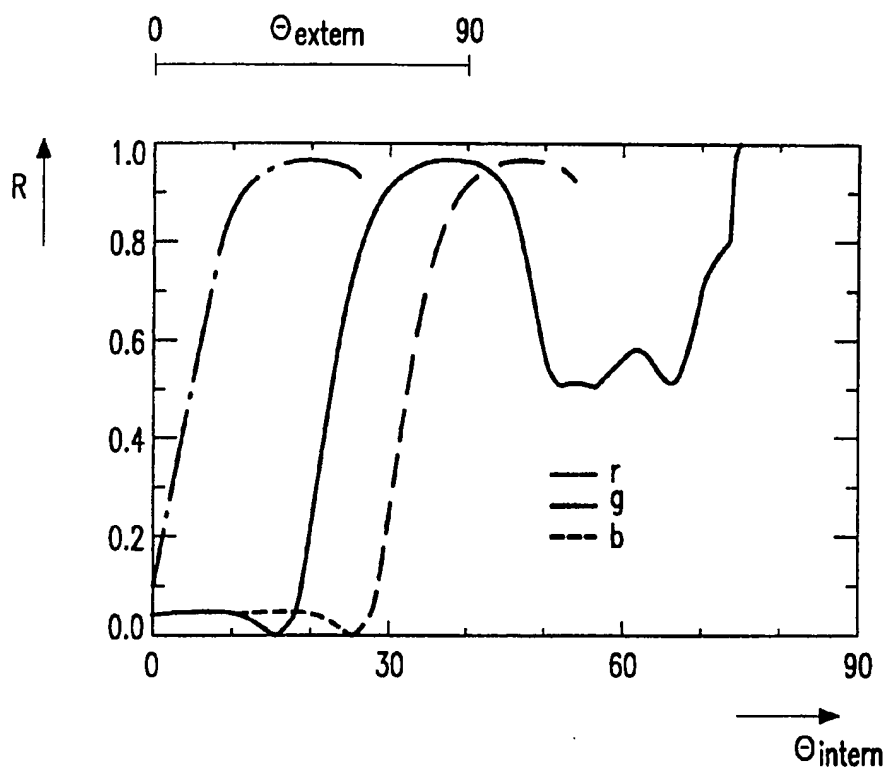


FIG. 6

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/IB 97/01299

<b>A. CLASSIFICATION OF SUBJECT MATTER</b>		
<b>IPC6: G02F 1/1335</b> According to International Patent Classification (IPC) or to both national classification and IPC		
<b>B. FIELDS SEARCHED</b>		
Minimum documentation searched (classification system followed by classification symbols)		
<b>IPC6: G02F</b>		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
<b>SE,DK,FI,N0 classes as above</b>		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
<b>WPI, CLAIMS</b>		
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5408344 A (Y. TAKIGUCHI ET AL.), 18 April 1995 (18.04.95), column 5, line 30 - column 9, line 2, figures 4-16, abstract  --	1,2,7,10
A	WO 9512826 A1 (MOTOROLA INC.), 11 May 1995 (11.05.95), page 6, line 8 - page 9, line 17, figures 2,3, abstract  --	1-10
A	US 5076668 A (A.L. DALISA ET AL.), 31 December 1991 (31.12.91), column 3, line 38 - column 10, line 68, figures 1-7  --	1-10
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "I" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search		Date of mailing of the international search report
27 March 1998		30 -03- 1998
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. + 46 8 666 02 86		Authorized officer  Karin Säfsten Telephone No. + 46 8 782 25 00

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/IB 97/01299

## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4456336 A (C.H. CHUNG ET AL.), 26 June 1984 (26.06.84), abstract  --	1-10
A,P	WO 9637805 A1 (POLAROID CORPORATION), 28 November 1996 (28.11.96), page 9, line 23 - page 15, line 8, figure 1, abstract  -- -----	1-10

**INTERNATIONAL SEARCH REPORT**  
Information on patent family members

02/03/98

International application No.  
PCT/IB 97/01299

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